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Multiple Criteria Inventory Classification for Storage Assignment and a Case Study

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Abstract. Warehouse management has been turned into a more complicated issue depending on dynamics pertain to customer, good, speed and cost. It's an inefficient and difficult approach to control all the stored items at the same level. Based on these; the main purpose of this study is bringing in a policy for warehouse management with the help of ABC Analysis via submitting the goods to inventory based classification. The goods will be assigned to slots according to their distances to the I/O point (Input/output point) by considering their importance orders at the end. In this context, DEMATEL method is utilized besides the Multi Criteria ABC Analysis methods used in literature. Initially Multi Criteria Decision Making techniques with weighted linear optimization, and in the following in order to make these calculations more accurate, calculation of cross evaluation of goods has been made in the literature. However, when we consider the calculation of cases which has increased numbers of goods, classification will be pretty hard. Thence, only cross evaluation points of goodsexceeding a threshold value when we apply DEMATEL method are calculated and applied to classification. On a model warehouse, mentioned techniques are benchmarked and it is shown that the approach, which is offered by us, reached similar or better results than the approaches in the literature in less time.
Keywords. ABC Analysis, Multi Criteria Decision Making, Warehouse Management.
JEL. M10, M11, M14.

1. Introduction

It becomes evident each passing day that key of managing supply chain more effectively is managing warehouses, which are the most important piece of logistic network, effectively. Owing to an efficient warehouse management, it is now obvious that progressing in many issues, which can accelerate company, such as quicker response to customer requirements, reducing warehouse costs and management of item variety is possible.Besides benefiting technology and suitable equipment selection, warehouse design also became significant in this context. Warehouse design can be performed with decisions taken in strategic, tactical and operational levels. Decisions made aboutwarehouse location selection, determining warehouse dimensions, determining capacity, selection of storage systems and technologies, and determining forward/reserve areasare strategic decisions. Tactical decisions are about storage assignment and product allocation. As for operational level decisions, they are about issues such as order picking, sorting or making lots.

A suitable storage assignment and product allocation provide significant improvements on order picking time and either on the issue of response for

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customer requirements. Furthermore, benefits such as faster order picking or product safety can be gained through considering the storage of products together, near or separate. Considering warehouse and storage costs, storage area usage prominently gains importance. This issue points out the necessity of effective performance of storage assignment and product allocation subsequently. Taking efficient steps in order to prevent the over need usage of storage area is possible via especially correct storage assignment and product allocation. It should be noted that this doesn't mean jamming items into slot. Target point is; allocating products in warehouse by reducing needed labor, contingent damage and accidents as much as possible, order picking time to minimal levels and by avoiding excess usage of storage space. Consequently due to forming product allocation in warehouse according to criteria those are derived from characteristics of products or decisions of decision makers (DM), ensuring optimizations in a spectrum of issues like reducing warehouse costs, occupational safety, effective usage of storage area and customer service level. In this context, products can be allocated to slots according to just one criterion or a systematic approach mentioned above and including many criteria.

ABC analysis is a method which is often applied and effective for product assignment and therefore inventory classification. This technique, which is so simple especially considering implementation and perception for personnel and managers, is based on Pareto Analysis. Class A consists of products which are least in number but most in handling cost and needs most of care and reviewing job. Because of these features class A products have priority in product allocation. Class C items constitute a majority of total product quantity. A more seldom review is enough for this group, and they are more durable. Class C products requires less transactions, thus they are cheaper in terms of handling costs. As a result of these statements, class C has no privilege on storage assignment. As for class B, they constitute the middle group. DMs can generate more classes. They can develop classes like AA, BB, CC or more besides classes A, B and C. DMs correspondingly make up classes' rates in total product quantity.

Traditional ABC analysis is based on annual dollar usage (annual demand* unit cost), and tried to be amended in terms of this perspective. Calculations are dealt with in many studies of literature by including more criteria which are quantitative and qualitative. Products are acknowledged as similar in consideration of their nature and the idea of varying of them in terms of their annual values is dominated in traditional ABC analysis (Ramanathan, 2006).

The purpose of this study is effectively improving the model offered by Park, Bae, and Bae (2014) utilizing Multi Criteria Decision Making (MCDM) techniques in order to conduct product allocation with ABC analysis by DEMATEL method to get more effective results in less time. Therefore benchmarking of values obtained as a result of subjecting same group of products of a sample warehouse successively to ABC analysis with such method and another linear model to determine product allocation to slots with the other values obtained by only implementing the method of Park, Bae, and Bae (2014) and product allocation of same linear model in terms of time and cost is dealt with in this study. Latter section mentions literature review, third section is about techniques used. In fourth section the implementation conducted as a case study and evidences obtained by this implementation are discussed. Finally fifth section is arranged as conclusion.

2. Literature review

Even methods such as TOPSIS, VIKOR, AHP etc. are tired to implement ABC analysis, Multi Criteria Decision Making technique is used in an important part of the literature. In those studies, a more objective approach is acquired by making each criterion gain its weight in the model itself through a method like data envelopment analysis (DEA) implementing weighted linear optimization. As is known, it’s debatable when inventory classification is done by asking DMs to determine weights of criteria in other given methods. As a result; in consideration of total effect of criteria on inventory classification, it is obvious that each criterion has its weight comparison to the other. Weights of criteria determined by criteria itself in model is more respected than determination with interventions out of the model.

Flores and Whybark (1986) can be called as the first study which asserts that it’s necessary to consider more criteria in inventory classification than handling just one criterion in traditional ABC analysis.Flores and Whybark (1987) supported their claim by improving their former study. Flores, Olson, and Dorai (1992) expressed that using AHP in inventory classification including more criteria is a quite convenient technique. At the same time, it is accepted as a self-criticism that obligation for DMs to grade so many times deals a blow to the process. Guvenir and Erel (1998) and Malmborg, Balachandran, & Kyle (1986) tried to realize ABC analysis with many criteria by developing heuristic methods in their studies. After these studies, Ramanathan (2006) is acclaimed with its DEA-like technique (hereafter R-model), and shaped so many latter studies.R-model caused DEA-like method to be the most emphasized technique of ABC analysis through MCDM Ng (2007) pointed out that it is possible to get classification easily without linear optimization by developing a formula (hereafter Ng-model) constituted by partial averages. But this study is criticized why it ignored weights of criteria in following studies. Hadi-Vencheh (2010) attempted improve Ng-model in this regard and reclassified inventory with a non-linear optimization including weights of criteria. Finally they benchmarked those two results. Zhou and Fan (2007), moreover, tried to gain a finer classification with the model they presented by improving R-model. Some criteria having relatively low level of importance but higher weight than it should be is observed in R-model. Because of this, in order to classify more correctly, a three-phase method is applied. Hatefi and Torabi (2010) agreed with the criticism of Zhou and Fan (2007) and offered a new model. Minimizing deviation of values giving the most efficient classification to find the optimal inventory scores which is lined for ABC analysis is attempted in this model. It is a mostly debatable topic that whether qualitative criteria are included besides quantitative ones or not.Criticality value of product is taken as “0.01, 0.5 and 1” to convert to number in R-model, but being discontinuous and not representing the given criterion enough in the model is criticized in some studies. Representation of qualitative criteria by random numbers, which are generated from the model, is thought to be more convenient in Torabi, Hatefi, and Saleck Pay (2012) due to the necessity of including qualitative and quantitative criteria together in the model. There are some other studies such as Bhattacharya, Sarkar, and Mukherjee (2007) and Chou, Chen, and Chen (2012) targeting to find the solution for ABC analysis with MCDM by using DEA-like technique. Another important study which is presented recently is Park, Bae, and Bae (2014). They dealt with criticisms of R-model about losing sensitivity and difficulty of classification due to having same inventory scores. After obtaining inventory scores with R-model, a model which considers effects of items on each other is conducted and finally average values of all points related to each product is figured out. These new values form the basis for ranking in Park, Bae, and Bae (2014). Thus criteria having same weight scores will be prevented and also a more sensitive ranking will be obtained.

3. Solution techniques used

3.1. DEMATEL

DEMATEL is an important technique to simplify solution process of related problem. The Decision Making Trial and Evaluation Laboratory (DEMATEL) method is developed between 1972 and 1976 years by Science and Human Affairs Programof the Battelle Memorial Institute of Geneva in order to use in solutions of problem which are complex and grift. DEMATEL is generated with the expectance of being initiator of usage of appropriate scientific research methods in order to contribute to defining applicable and hierarchical solutions, and improving comprehension of grift problems. DEMATEL method working on the basis of graph theory, enables us to plan problems in outline and solve by separating factors, which provide better understanding of causal relation to us, into cause and effect groups (Aksakal & Dağdeviren, 2010).

DMs don't only make calculations easier, but also find the possibility of making analysis through DEMATEL. Therefore DMs separate multi-dimension criteria into cause and effect groups in order to comprehend causal relations easily. Furthermore, directed graphical lines, also called as digraphs, are more elucidative why they better clarify directed relations between subsystems. A digraph represents communication network and dominant relations between entities and groups of them in other words (Chen & Chen, 2010).

DEMATEL is q quite efficient method which helps to collect data in groups and easily understand the problem by dealing with interrelations of subsystems. Owing to this feature, dynamics of problem is determined in an easier way. And then only the dynamic, which has notable effect, are included in solution, so this makes problem easier.

DEMATEL is consisted of five steps (Aksakal & Dağdeviren, 2010):

Step 1: Determine direct relation matrix (H). Direct relations between criteria are scored using pairwise comparison scale by DMs. Average of these scores forms direct relation matrix. Diagonal values are "0" in this matrix.

Table 1: Pairwise Comparison Scale.

Numerical Value	Definition
0	No influence
1	Low influence
2	Medium influence
3	High influence
4	Very high influence

Step 2: Find normalized direct relation matrix (X) by using "H" matrix.

$$X=k.H \qquad \text{(eq. 1)}$$

$$k = Min\left(\frac{1}{max_{1\le i\le n}\sum_{j=1}^{n} a_{ij}}, \frac{1}{max_{1\le j\le n}\sum_{i=1}^{n} a_{ij}}\right), i,j = 1,2,\ldots,n. \qquad \text{(eq.2)}$$

Step 3: Identify total relation matrix (T) using matrix "X" and equation 3. "I" stands for identical matrix.

$$T=X\,(I-X)^{-1} \qquad \text{(eq. 3)}$$

Step 4: Determine cause and effect groups. Sum of rows and columns successively form "D" and "R" in "T" matrix. "D+R" shows the importance of criterion, on the other hand "D-R" defines the interrelation of criterion by separating them into cause and effect groups.If "D-R" is positive, criterion is of cause otherwise effect group.

Step 5: Designate threshold value and proceed to calculations. DMs or experts should designate a suitable threshold value to obtain an effective calculation. Only the values exceed in threshold value can find place in calculation.

3.2. Cross Evaluation Based Weighted Linear Optimization with DEMATEL

As it mentioned before; in order to subject products to ABC analysis to figure out optimal inventory scores of products in Park, Bae, and Bae (2014), a new ranking score is obtained executing cross evaluation, in other words evaluating effects on each other, of products in new model proposed using values obtained by a linear optimization model consisting of performances of products under determined criteria and weights of these criteria. Park, Bae, and Bae (2014) call this method as Cross Evaluation Based Weighted Linear Optimization (CEWLO).

Many critics made in former studies, such as ranking scores not differentiating enough or misleading of scores found as a result of criterion having a dominant value on another even it doesn't have that importance, are scoped out through CEWLO. Among optimal inventory scores obtained in R-model, many items get same values. Separation of product list into A, B and C groups during ABC analysis isn't that possible or implemented with enough sensitivity naturally. When the same problem is solved with CEWLO, number of products having same value is little or none. Another positive side of implementing ABC analysis with CEWLO is considering not only cross effects of criteria but also cross effects of products, and calculating ranking scores in the light of this approach. Therefore, issues such as product allocation in warehouse, order picking or transactions during storage life, are included into the model. This consideration is not totally effective but improves the implementation. R-model and CEWLO is successively given in equations 4-6 and equations 7-11.

$$I_k = Max\ \sum_{r=1}^{s} u_{rk} y_{rk} \quad \text{(eq. 4)}$$
$$s.t. \sum_{r=1}^{s} u_{rk} y_{rj} \leq 1, \ \ j = 1, \dots, n, \quad \text{(eq. 5)}$$
$$u_{rk} \geq 0, \qquad \forall r. \quad \text{(eq. 6)}$$
$$c_{pk} = Min\ \sum_{r=1}^{s} u_{rk} y_{rp} \quad \text{(eq. 7)}$$
$$s.t. \sum_{r=1}^{s} u_{rk} y_{rk} = I_k^* \quad \text{(eq. 8)}$$
$$\sum_{r=1}^{s} u_{rk} y_{rj} \leq 1; \quad j = 1, \dots, n, j \neq k \quad \text{(eq. 9)}$$
$$u_{rk} \geq 0 \ \ \forall r \quad \text{(eq. 10)}$$
$$I_p = \frac{\sum_{k=1}^{n} c_{pk}^*}{n}, \ \ p = 1, \dots, n \quad \text{(eq. 11)}$$

If we mention lacking sides of CEWLO beside positive sides, we can criticize it about spending so much time even for a few products because of the model's complexity. As for implementing DEMATEL with contribution of DMs and process experts after stating main groups, it makes us save time while getting the same results. While implementing DEMATEL, importance of determining threshold value is so high. Ranking scores, ABC analysis and the cost of product allocation varies depending on threshold value. There is no rational way of stating threshold value. The threshold value is totally determined via trial and error method through the directions of DMs and/or process experts. According to the threshold value that is set, it's possible to have less product allocation cost obtained through analysis and calculation than the cost figured out only with CEWLO besides a significant saving of calculation time.Product allocation and cost account of a ten-item product list given as an example in Park, Bae, and Bae (2014) is fulfilled through ABC analysis and the integration of CEWLO and DEMATEL in the next section.

4. Implementation

An implementation is realized on products of a governmental and non-commercial warehouse utilizing DEMATEL besides R-model and CEWLO. In this section; implementation phases of DEMATEL, ABC analysis which is implemented on products ranking obtained by given methods, product allocation and total cost of this allocation realized through this process are given.

Initially, product sample consisting of ten items is separated into five main groups. These product groups are iron-welding products, electrical products, carpentry products, sanitary products and finally building products. Product groups are successively represented by IG1, IG2, IG3, IG4 and IG5.

Direct relation matrix is formed by scoring product groups by DMs as to pairwise comparison scale given in Table 1 in first step.

Table 2. *Direct Relation Matrix.*

H Matrix	IG1	IG2	IG3	IG4	IG5	Sum of Rows
IG1	0	1,333333	1	1,333333	1,666667	5,3333333
IG2	2,333333	0	1,666667	2,333333	2,666667	9
IG3	2,666667	1	0	1	1,333333	6
IG4	4	2	1,666667	0	3	10,666667
IG5	4	2	2	2	0	10
Sum of Columns	13	6,333333	6,333333	6,666667	8,666667	

The constant "k" is calculated using formula shown in equation 2 and sum of rows and coloumns and found as "k= 0,07692" in the second step. Normalized direct relation matrix "X" is obtained using the constant "k" and direct relation matrix "H" given in equation 1.

Table 3. *Normalized Direct Relation Matrix.*

X Matrix	IG1	IG2	IG3	IG4	IG5
IG1	0	0,102564103	0,076923077	0,102564103	0,128205128
IG2	0,179487179	0	0,128205128	0,179487179	0,205128205
IG3	0,205128205	0,076923077	0	0,076923077	0,102564103
IG4	0,307692308	0,153846154	0,128205128	0	0,230769231
IG5	0,307692308	0,153846154	0,153846154	0,153846154	0

In third step, total relation matrix "T" is obtained implementing formula in equation 3 with normalized direct relation matrix "X" and identical matrix "I".

Table 4. *Total Relation Matrix.*

T Matrix	IG1	IG2	IG3	IG4	IG5	D
IG1	0,23119	0,217407	0,193154	0,222238	0,273538	1,1375274
IG2	0,518025	0,196919	0,304514	0,356851	0,425518	1,801826
IG3	0,406479	0,198362	0,121873	0,20277	0,254659	1,1841421
IG4	0,654103	0,354009	0,326042	0,228543	0,473427	2,0361234
IG5	0,62169	0,336016	0,329036	0,343483	0,261643	1,8918687
R	2,431486	1,302713	1,274619	1,353885	1,688784	

"D" value consisting of rows sum and "R" value consisting of columns sum are figured out using values in "T" matrix in fourth step. "D, R, D+R and D-R" are given in Table 5. As it mentioned before, "D+R" indicates the importance level of criterion, and "D-R" indicates the relation between criteria forming cause and effect group. A positive "D-R" value means the criterion is of cause group, negative one means the criterion is of effect group.

Table 5. *Cause and Effect Groups.*

	D	R	D+R	D-R	GROUP
IG1	1,137527	2,431486	3,569014	-1,29396	Effect
IG2	1,801826	1,302713	3,104539	0,499113	Cause
IG3	1,184142	1,274619	2,458761	-0,09048	Effect
IG4	2,036123	1,353885	3,390008	0,682239	Cause
IG5	1,891869	1,688784	3,580653	0,203085	Cause

After determining cause and effect groups, fifth step is implemented. DMs initially must state an efficient threshold value in fifth step. It's important to determine threshold value correctly why the criteria having scores over this value will be included in calculations. Otherwise unimportant relations can be included in calculations or important ones can be excluded, so implementation of DEMATEL can be meaningless. Threshold value is accepted as "0.23" as a result of several trials in our study. Relations only having value exceeding threshold value are considered in CEWLO calculations.

Optimal inventory scores figured out through DEA-like method in R-model, CEWLO and DEMATEL, and ABC analysis which is implemented depending on these scores are given in Table 6.

Table 6. *ABC Analysis.*

	R-Model		CEWLO		DEMATEL-CEWLO	
Item Code	Optimal Inventory Score	Class	Optimal Inventory Score	Class	Optimal Inventory Score	Class
G1	94,81376	C	0,312318335	C	0,245313492	C
G2	100	A	0,540847345	B	0,566167941	B
G3	100	C	0,355293	C	0,256615791	C
G4	50	C	0,111412778	C	0,075515972	C
G5	100	A	0,50260771	B	0,254019275	C
G6	39,39491	C	0,147608363	C	0,11701051	C
G7	100	B	0,576148858	B	0,528904933	B
G8	73,48754	C	0,302774217	C	0,286608341	B
G9	100	B	0,581000553	A	0,581000553	A
G10	100	B	0,677407464	A	0,677407464	A

Considering optimal inventory scores and results of ABC analysis, the issue of many products possessing the same score and the increased difficulty of this issue pertain to ABC analysis can be realized. It can be seen that optimal inventory scores found through integrated DEMATEL & CEWLO are more distinctive. Having implemented this integrated model to the same product group, only two products become members of different classes from the other method. Product allocation of integrated model, total cost of this allocation and needed time for calculation are successively given in Table 7 and Table 8.

The cost which is occurred as a result of product allocation is calculated through a linear model formed using handling quantity in a period, needed number of slots and the distance of slots to warehouse input / output point or points. A warehouse with only one input / output point using this door for all transactions in and out is presumed in this study. The model turns into a more simple form then. Products' allocation to the slots in warehouse is realized by matching optimal inventory scores list which is ranked in descending order with distances of slots to input / output points which are ranked in ascending order (Askin & Standridge, 1993).

Table 7. *Product Allocation.*

Slot	R-Model	CEWLO	DEMATEL-CEWLO
	Item Code	Item Code	Item Code
S1	G2	G10	G10
S16	G2	G10	G10

S6	G2	G10	G10
S21	G2	G10	G10
S2	G5	G9	G9
S17	G5	G9	G9
S11	G7	G7	G2
S26	G7	G7	G2
S7	G7	G7	G2
S22	G7	G7	G2
S3	G9	G2	G7
S18	G9	G2	G7
S12	G10	G2	G7
S27	G10	G2	G7
S8	G10	G5	G8
S23	G10	G5	G8
S4	G3	G3	G3
S19	G3	G3	G3
S13	G1	G1	G5
S28	G1	G1	G5
S9	G8	G8	G1
S24	G8	G8	G1
S5	G4	G6	G6
S20	G4	G6	G6
S14	G4	G4	G4
S29	G4	G4	G4
S10	G4	G4	G4
S25	G4	G4	G4
S15	G6	G4	G4
S30	G6	G4	G4

Table 8. Product Allocation Cost.

Method	Cost	Time
R-Model	333,13	4 seconds
CEWLO	226,73	34 seconds
DEMATEL-CEWLO	226,73	24 seconds

5. Conclusion

Companies have the chance of managing products in warehouse more effectively through ABC analysis. Owing to this method; a particular policy will be applied on location assignment besides reviewing and controlling products as to their importance level. Products such as used more frequently, cost more or more delicate etc. can be allocated to a more suitable slot in warehouse. The method presented in R-model lacks in reaching efficient results solely, even it serves as a basis for other methods mentioned in this study. As for CEWLO presented in Park, Bae, and Bae (2014), it proves that it can realize management of products in warehouse cheaper than DEA-like method considering total assignment cost. However considering larger sample of products, the risk of exposing so long calculation time shouldn't be ignored. Today the big increase on product variety and customer demands causes a quite many increase on the quantity and variety of products which a company must store. In view of the circumstances, trying to implement ABC analysis with CEWLO loses efficiency. In such a case; utilizing DEMATEL seems quite beneficial.

When DEMATEL technique is implemented, some revenues can be gained from product allocation cost in some samples, besides the substantial saving of time. The focal point is determining threshold value correctly. Calculation time and cost as a result of product allocation differ as to selected threshold value. DMs are naturally given the most significant task. DMs are needed to be in command of enough detail about logistic processes and product groups. They can construe the process better and determine correct threshold value only in this manner. Class A products are allocated to the slots which are nearer to input / output point and products of class B and C are allocated to the slots in comparison to the distance from input/ output point via product allocation method and ABC analysis after determining suitable threshold value. A more efficient and finer warehouse management can be achieved in exchange for less labor cost through this approach.

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